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The settlement and survival of young mussels in the Conway fishery

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ABSTRACT

Observations on mussel settlement on the intertidal beds at Conway were made over a period of five years from 1961–65. These included one year, 1962, when the settlement was exceptionally heavy, and one winter, 1962–63, which was exceptionally cold. The possible relation between heavy spatfall and cold winters is discussed.

Evidence is presented on the role of the shore crab, *Carcinus maenas*, as a predator of mussels.

The sublittoral mussel beds were surveyed and the size distribution of the population determined on three occasions at six-monthly intervals. In some cases it is possible to follow the fate of a particular size group through the three surveys and so gain information on growth-rates, and the effect of fishing on the stocks. It is shown that in the River Conway it takes about four years for mussels to grow to the market size of 60–70 mm.

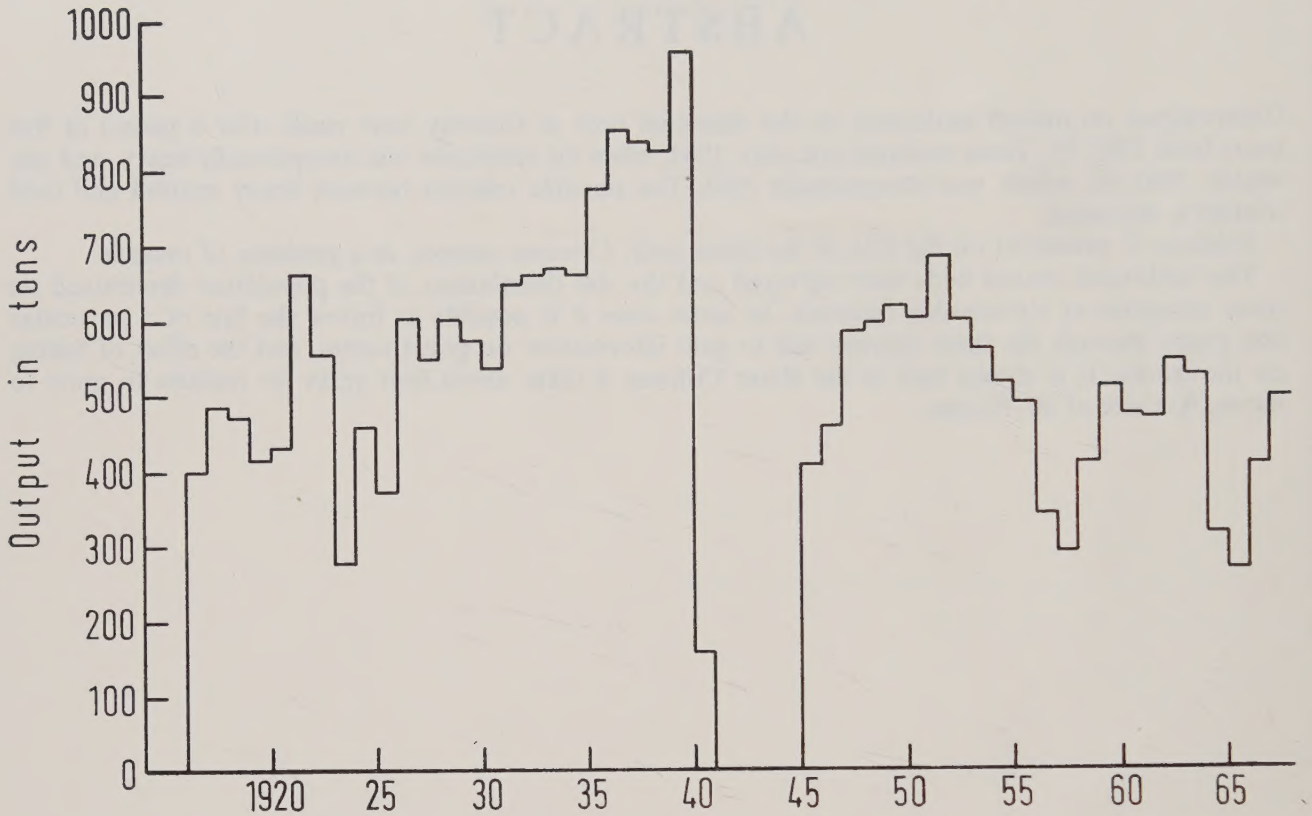

Figure 1 Annual output figures for the Conway mussel fishery from 1916 to 1966.

PART I
OBSERVATIONS ON THE INTERTIDAL BEDS

INTRODUCTION

The Conway mussel fishery is an ancient industry, although in Roman and mediaeval times it appears to have been concerned mainly with the production of pearls. It is not known when it became a food industry, but it was probably at least a century ago, nor are there any records of the quantities of mussels produced in the earlier years. Accurate records date from about 1916, when the mussel cleansing tanks were installed and all mussels sold for human consumption had to pass through them. Annual output figures from 1916 to the present time are shown in Figure 1. In the early years of this period the yield was much the same as in recent years, 400–500 tons per annum. In the interim there have been many fluctuations in the output, perhaps the most dramatic being the high peak in the 1939–40 season, with a figure of 950 tons; this was followed by the complete collapse of the fishery for most of the war years, due to the fact that an enormous spatfall of mussels in the spring of 1940 so blanketed the beds that all the adult mussels were smothered (Savage 1956).

We have little information on the causes of these fluctuations in output. The methods used by the fishermen have not changed much; hand-gathering, and raking from small boats are the two methods used for collecting mussels (Plates 1 and 2), and these have remained unchanged since the fishery began. Motors have replaced sails as a means of propulsion and, whereas each boat used to travel independently, it is now usual for a motor launch to tow several dinghies, this being especially true of the larger gangs.

The number of men engaged in the fishery has varied widely. In 1929, the earliest year for which we have records, 55 licences to fish mussels were issued by the Conway Borough Council; the number rose steadily to 70 in 1938, and to 96 in 1939. In post-war years it has varied between about 30 and 50. Although there is a broad relation between the number of men fishing and the quantity of mussels produced, to say that the one was the cause of the other would be an over-simplification of the case. The scarcity, or otherwise, of mussels will undoubtedly affect the number of men taking out licences, but the availability of other employment is perhaps a more important factor. The increase in the amount of industry in the area since the war may well account for the general reduction in the numbers of licences issued, as compared with pre-war years. However, leaving aside for the moment the question of whether the one factor is the cause or the effect of the other, it must be true that the supply of mussels was greater in the late 1930s than it has been recently. At that time the output of the fishery was rising rapidly and an output of over 800 tons was achieved in four successive years, whereas in recent years the output has rarely exceeded 500 tons and at times marketable mussels have become extremely scarce on the beds.

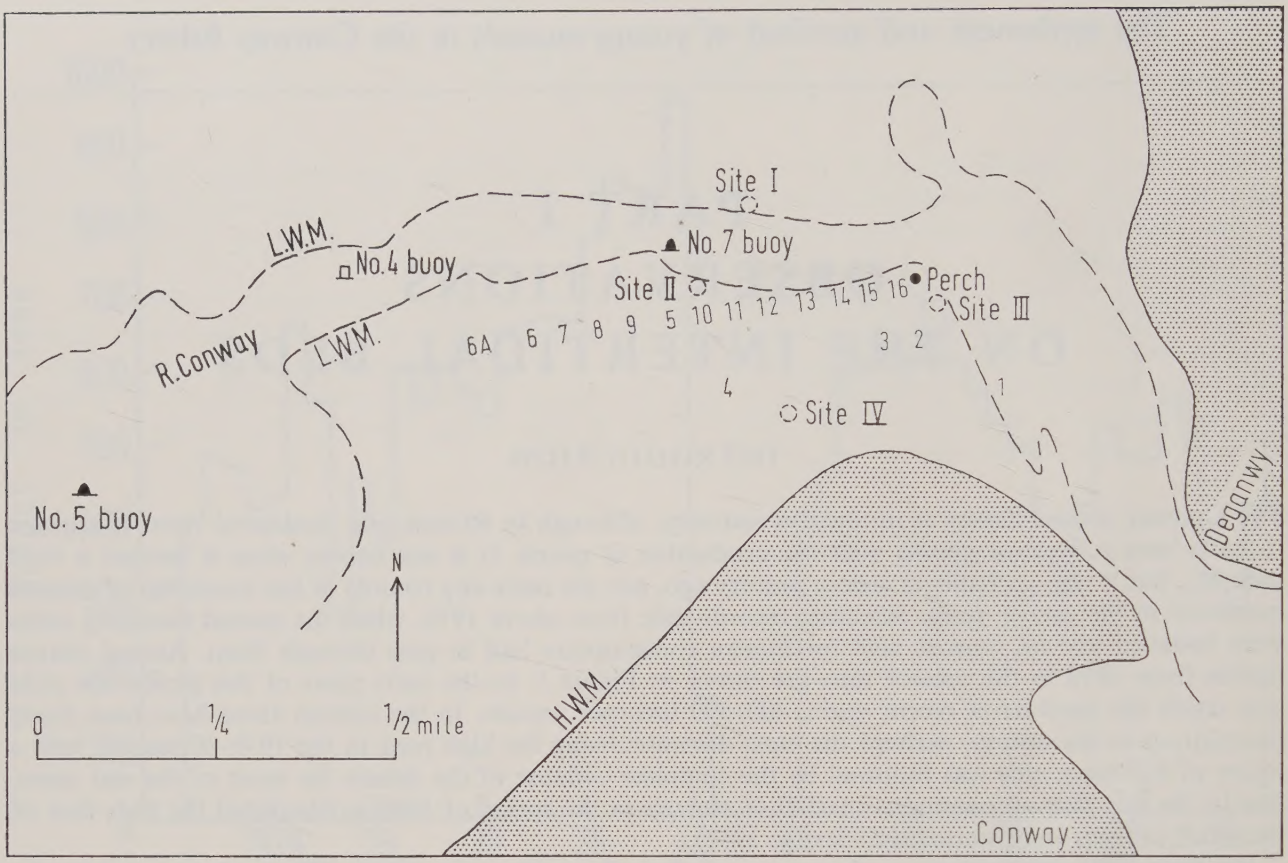

Figure 2 Sketch map of the Conway estuary, showing the four intertidal mussel-sampling sites and the positions of the mussel spat collectors.

METHODS

When this work was started in 1961 it was thought that good mussel settlements were relatively rare and only occurred at intervals of several years. It was not known whether this was due to a failure of the mussels to spawn regularly or to a failure of the young mussels to survive. If the mussels spawned but the larvae failed to find a suitable place to settle, it seemed that it might be desirable to provide an artificial surface to encourage settlement. The main objects of the present work were to gain information on the time of year when mussel settlement occurred, the density of settlements, and whether they occurred over the whole beds or only in certain areas. With this in mind observations were started at four sites, all of which dried out at low water (Figure 2).

Site I lay on the north side of the Conway channel, opposite No. 7 buoy, at the level of low water of a moderate spring tide. The ground sloped steeply to the channel and was composed of pebbles and gravel with some sand. The ebb tide ran strongly in that area.

Site II was on the opposite side of the channel, near No. 7 buoy. The level was a little above spring tide low water. The ground was fairly level, mainly gravel and sand, with less tidal scour than at Site I.

Site III, on the west bank of the channel near the Perch, was at about low-water mark of neap tides. The ground was mainly sandy, formed into large ridges, covered with mussels.

Site IV was quite different from the others, because it was at a level approaching the half-tide mark. The ground was flat, composed of sand and gravel, and was carpeted with mussels which were practically all less than 15 mm in length when the observations started.

After some experimenting it was decided to take five sub-samples, each covering 1/50 sq. metre, for each sample, and to express the results as counts per 1/10 sq. metre. These were not taken as truly random samples, because on some sites only about a quarter of the ground actually carried mussels. For this reason the sub-samples were taken as randomly as possible on patches of mussels. A suitably-sized square of wood was placed on the ground and the mussel carpet was cut round it with a knife. The square of mussels was then lifted and placed in a bag. Each sample was brought back to the laboratory and carefully washed over a series of four sieves, of which the finest had a 1 mm mesh. The mussels were then carefully separated from each other, and from debris, in a white dish. A good light was essential for this work since the very small mussels were often hard to see, due to variations in shade from almost colourless to black. After separation they were placed in size groups of 3 mm up to 9 mm in length, and of 5 mm from 10 mm upwards. Starting in February 1962 each site was sampled at monthly intervals until November, and some observations were made in the following year. Prior to this some observations had been made at Site IV in December 1961, and at Site I from July 1961 onwards. The results are given in Tables 1–4.

Of the four sampling points Site IV (Table 4) gives the clearest picture, perhaps because this site was clothed in an even carpet of mussels and lent itself to this type of sampling programme. In February 1962 the most numerous size group was undoubtedly the 0–3 mm, and there were very few mussels over 14 mm in length. From February to July there was a general decrease in the numbers in all size groups, and this was most marked in the 0–3 mm group which fell from 1 782 to 82 per 1/10 sq. metre. By July the population had a well-marked mode from 7–19 mm, resembling that of a year-class, which persisted quite clearly through to November. The number of mussels in the modal group decreased fairly steadily, but their average size increased from about 13 mm in July to 20 mm in November.

Recruitment in the 0–3 mm group started in August and continued until November, by which time there were over 10 000 per 1/10 sq. metre. There was also some growth in these small mussels, which resulted in a rise in the count in the 4–6 mm group in October and in the 7–9 mm group in November. The growth of the larger mussels in this population is also shown by the fact that although there were only 3 per 1/10 sq. metre in the 20–24 mm group in February, there were 206 in November. These results are what would be expected from the interaction of predation, recruitment and growth.

Sites I, II and III were all virtually low-water sites which allowed the mussels to grow to about 70 mm in length. In all cases the distribution of mussels was patchy and this made sampling more difficult. These sites were all fished regularly during the winter months; during the period in question fishing stopped in March and was resumed in September. One might have expected that during the summer months the absence of fishing, and the higher summer growth-rate, would result in an increase in the numbers of mussels in the larger size groups, and that there would be, in effect, a restocking of the fishery with mussels of market size (i.e. over 55 mm in length). However, none of the three low-water sites showed this. It seems probable that the samples taken contained too few large mussels to yield significant information about their growth.

Turning to the smaller size groups (where the numbers of mussels were much greater), we find that the picture obtained at Sites I to III is broadly similar to that from Site IV. Settlement of mussels of the 0–3 group started in July and continued throughout the summer and autumn (Tables 1, 2 and 3). In May and June the counts of this group were less than 100 per 1/10 sq. metre at all three sites, but in July they rose to about 1 000 and by September they averaged over 2 000, the numbers continuing at much the same level through October. It should be emphasized that at this stage no sign of a spatfall was visible on the beds to a casual observer; these tiny mussels could only be detected by the careful examination of samples in the laboratory. By March 1963, however, small mussels could be seen among the adults and on stones on the beds in large numbers. A general survey made early in April showed that the greater part of the fishery was covered with mussels which were mainly 4–7 mm long and obvious on quite casual inspection. The heavy spatfall was not confined to Conway. Extensive settlements were reported from many places on the east coast, and also from some places on the west coast, but not in the Menai Straits, near Bangor.

Table 1 Numbers of mussels of various sizes per 1/10 sq. metre at Site I

Size (mm)	1962 February	March	April	May	June	July	August	September	October
0– 3	127	117	107	33	24	138	1 079	2 625	1 646
4– 6	27	27	22	41	44	14	20	172	118
7– 9	21	12	8	4	32	7	4	16	20
10–14	6	14	7	8	26	14	11	3	4
15–19	9	8	14	4	9	1	6	11	6
20–24	8	10	12	9	12	2	8	4	7
25–29	8	16	12	9	9	3	4	4	6
30–34	7	11	8	6	9	9	7	3	5
35–39	8	9	3	15	6	9	17	7	9
40–44	13	9	9	7	4	6	9	6	16
45–49	15	20	19	15	7	14	11	11	10
50–54	16	13	15	13	24	19	11	14	12
55–59	5	9	11	16	17	9	14	8	9
60–64	8	5	6	6	8	11	8	10	15
65–69	2	3	2	4	4	4	2	0	2
70–74	1	0	0	0	0	0	0	0	–
75–79	0	0	1	0	0	0	0	0	1
Total*	16	17	20	26	29	24	24	18	27

* Totals over 55 mm only

Table 2 Numbers of mussels of various sizes per 1/10 sq. metre at Site II

Size (mm)	1962 February	March	April	May	June	July	August	September	October	1963 June
0– 3	41	54	84	58	43	938	1 100	2 020	1 736	750
4– 6	9	4	19	33	55	12	34	73	69	850
7– 9	4	2	8	8	36	13	12	10	16	40
10–14	5	0	4	4	12	23	21	9	11	75
15–19	7	5	18	5	6	10	17	14	12	20
20–24	4	5	8	7	7	3	9	11	13	10
25–29	9	3	14	3	9	5	5	4	12	5
30–34	5	8	6	4	16	6	3	3	9	35
35–39	1	4	7	3	12	9	9	8	5	10
40–44	5	11	15	6	12	9	6	10	15	20
45–49	11	13	20	11	6	9	7	5	10	15
50–54	13	15	18	19	13	10	7	6	10	5
55–59	11	12	18	21	12	7	13	15	5	10
60–64	9	7	4	10	1	5	7	16	8	15
65–69	3	2	2	7	0	1	1	2	3	5
70–74	4	0	0	0	0	0	0	0	1	0
Total*	27	21	24	38	13	13	21	33	17	30

Table 3 Numbers of mussels of various sizes per 1/10 sq. metre at Site III

Size (mm)	1962 February	March	April	May	June	July	August	September	October
0– 3	275	102	62	76	40	1 196	2 314	1 778	2 198
4– 6	70	39	26	24	48	36	45	48	137
7– 9	46	32	10	12	21	19	32	5	22
10–14	23	23	10	13	18	14	26	7	28
15–19	41	18	10	5	11	9	15	7	9
20–24	20	14	10	8	15	18	23	3	12
25–29	11	7	9	6	7	15	16	6	4
30–34	15	15	11	12	11	8	11	3	7
35–39	19	20	17	11	16	12	7	5	12
40–44	20	16	8	18	16	18	12	11	10
45–49	23	34	12	25	20	19	21	15	20
50–54	38	35	22	15	27	23	22	17	22
55–59	21	14	14	7	4	7	14	11	11
60–64	6	2	2	1	1	3	5	3	2
65–69	1	0	3	1	0	1	0	1	0
70–74	0	0	0	0	0	0	0	0	0
Total*	28	16	19	9	5	11	19	15	13

Table 4 Numbers of mussels of various sizes per 1/10 sq. metre at Site IV

Size (mm)	1962 February	March	April	May	June	July	August	September	October	November
0– 3	1 782	1 644	1 351	878	237	82	483	4 711	3 727	10 440
4– 6	558	333	556	497	382	80	45	36	70	470
7– 9	352	233	330	351	261	174	85	54	35	60
10–14	298	393	386	482	497	284	215	176	110	93
15–19	64	171	152	153	218	248	253	278	183	185
20–24	3	21	26	5	40	68	93	112	136	206
25–29			4		2	5	33	10	30	34
30–34					0			1	1	0
35–39					1				1	1

By mid-June 1963 those mussels which had settled in sheltered niches were growing well but the great majority of those on exposed surfaces had disappeared. While they could shelter between the barnacles they were safe, but when they grew too big for that they became very vulnerable to birds such as seagulls and oystercatchers, when the tide was out, and marine predators when the tide was in. It became clear that we had witnessed a substantial and widespread spatfall on the Conway beds.

It was mentioned above that some observations had been made at Site I between July and November 1961. Some counts were made on single samples of approximately 1/50 sq. metre, i.e. one-fifth of the size of the samples taken later. In mid-July a count of 79 mussels of the 0–3 mm group was obtained; this rose to 1 420 in late August, and fell to 435 by mid-September and to 183 by November. The settlement in July and August was similar to that in the following year but from August onwards the two years were quite dissimilar. In 1961 there was a heavy autumn mortality of the young mussels, but in 1962 either this was negligible, or it was compensated for by continued heavy settlement.

USE OF SPAT COLLECTORS

Although the examination of ground samples yielded valuable information, the extremely slow growth of some of the very small (1 mm) mussels made it impossible to tell how long the spatfall lasted. A marked increase in the numbers of small mussels from one month to the next could certainly be taken as indicative of a settlement, but if large numbers were present on successive occasions there was no means of telling whether they were the same ones, or whether there had been a substantial mortality which was compensated for by a continued spatfall. Another limitation of the method was that, although it gave information about settlement on ground suitable for mussels, it conveyed nothing about mussel settlement on ground such as loose sand, where mussels could not survive. To overcome these limitations it was decided to put up spat collectors which could be examined at regular intervals. These collectors were suspended from wooden T pieces, clear of the bottom to reduce the risk of predation by crabs, at six positions (Nos. 1 to 6) as shown in Figure 2.

In the initial experiments, mussel shells suspended on courlene twine were used as collectors. Settlement on the shells took place entirely on the under (concave) side, and mainly in the pointed end or round the hole where the twine passed through. Spat also settled freely on the twine, especially on the knots which were tied in it to space out the shells. The frequency with which spat settled on the twine led to the development of a collector without shells. A flat sennit of twine 6 inches long was tried (Plate 3); this offered a large number of niches which appeared to be suitable for settlement, and had the advantage of presenting a more standard surface than a collection of mussel shells. In April and May 1964 both types of collectors were used side by side. Settlement at that time was light and unevenly distributed; racks 3 and 5 were the only ones to collect any appreciable numbers of mussels, and the counts obtained were as follows:

		17 April	4 May
Rack 3	Shells	85	56, 81
	Sennit	29	39, 104
Rack 5	Shells	1	15, 13
	Sennit	43	12, 10

As there was no consistent difference between the counts of the two types of collector, and as the flat sennit gave a surface whose nature and area could be standardized, and was also easier to make and to count, it was adopted as the standard collector.

From May to August 1964 the collectors at positions 1–6 were in use. Three collectors were hung on each rack, and they were changed at fortnightly intervals. Rack 2, which was placed in a wide shallow gutter of loose sand, gave no results, because the moving sand ridges buried it or allowed it to wash away. Rack 6 also needed frequent replacement because it was frequently broken. As it was sited on hard level sand to the seaward side of the mussel beds, it is thought it may have been damaged by either wave action or amateur trawlers. Wave action seems to be the less likely explanation, since on one occasion a rack attached to a five-foot length of $\frac{3}{4}$ inch steel tube driven three feet into the sand was missing within a week. Interference by holiday-makers on the beach was also possible.

The numbers of mussels found on the collectors are shown in Table 5, each of the three collectors on each rack being shown separately. Broadly speaking, racks 1, 3 and 5 were situated in mussel beds and it will be noted that most of the settlement occurred on them. As mentioned above, rack 2 gave no useful results except to demonstrate the mobility of the ridges of loose sand. Although rack 6 was difficult to maintain there was some settlement there in July and August, which suggests that the complete absence of mussels on the flat areas of hard sand is due to the unsuitable nature of the ground and not to a lack of available spat. Further evidence on this point was obtained from rack 6A which was placed 80 yards seaward of rack 6 at the end of July 1965, and which collected a few mussels. The sparse settlement on rack 4 was unexpected because this was situated in the same area as Site IV, from which ground samples had been taken and which was clothed in a carpet of mussels.

Table 5 Numbers of mussel spat which settled on the three collectors on each of racks 1–6 in fortnightly periods during the summer of 1964

Rack no.	19 May	1 June	16 June	29 June	14 July	28 July	11 August	26 August
1	–	–	–	2, 0, 2	2, 0, 0	2, 8, 5	2, 1, 1	1, 0, 0
2	–	–	–	–	0, 0, 0	–	–	–
3	2, 1, 2	0, 0, 0	0, 0, 0	11, 0, 2	10, 11, 16	6, 3, 8	1, 2, 3	0, 1, 2
4	0, 0, 0	0, 0, 0	0, 0, 0	2, 4, 0	–	0, 0, 0	1, 2, 0	0, 1, 0
5	2, 8, 1	0, 1, 0	0, 1, 1	0, 0, 0	15, 6, 19	17, 15, 17	12, 13, 25	7, 6, 4
6	–	–	–	–	0, 1, 4	2, 0, 0	2, 0, 0	2, 0, 0

Table 6 The spat settlement at Conway Morfa in 1965, shown as the total numbers on the three sennit collectors ('strings'), each of area approximately 4½ sq. inches, at each rack. The figures in italics give the numbers of mussels less than 4 mm long per 1/50 sq. metre on the ground in the same position

Rack no.	Date counted									
	21 January	15 February	15 March	29 April	31 May	28 June	29 July	26 August	27 September	21 October
16	–	0	0	0	M	0	26	M	0	0
						0	*349*	*149*	*31*	*12*
15	–	0	0	0	0	0	M	M	0	0
14	–	0	1	M	0	0	22	0	0	0
13	1	0	0	0	0	0	14	1	0	0
12	1	0	0	0	0	0	22	0	0	0
11	0	0	0	0	M	0	22	0	0	0
10	0	0	0	0	0	3	43	1	M	0
5	1	0	0	M	0	1	64	0	M	0
						15	*72*	*50*	*6*	*1*
9	–	0	0	0	0	4	90	2	0	0
8	0	0	0	0	0	M	123	4	0	0
						12	*464*	*70*	*0*	
7	–	0	0	2	0	12	113	3	0	0
6	–	–	0	M	M	4	119	3	0	M
6A	–	–	–	–	–	–	–	7	0	1

Note Rack 6A was first put down on 30 July. M = rack, or strings, missing.

By mid-1964 it had become evident that there were interesting variations in the density of spatfall in different parts of the mussel bed. Experience of previous years had suggested that settlement was likely to continue into September and October. It was thought that more useful information would be gained from the spat collectors if they were arranged at regular intervals along a straight line across the mussel bed, and extending over the bare sand at either end. Accordingly in August 1964 new racks numbered from 7 to 16 were placed at 80-yard intervals as indicated on Figure 2, and positions 1, 2, 3 and 4 were abandoned. Observations were continued regularly through the remaining months of 1964 and throughout 1965. In addition, from June 1964 onwards, at three of the stations (5, 8 and 16) a ground sample of 1/50 sq. metre was examined at monthly intervals; the numbers of mussels less than 4 mm long present in these samples are shown in italics in Table 6, in which the 1965 observations are summarized.

During the period from the end of August to December 1964 there was practically no settlement of spat. In 1965 the settlement may be said to have occurred almost entirely in July, with only a slight overlap into the preceding and following months. This was true of both the collectors and the ground samples. The main weight of the settlement was at the western end of the line, and the second highest number of mussels was recorded on rack 6, on the sand. This adds to the evidence of the previous year that the absence of mussels on the sandy ground was due to its unsuitable nature and not to lack of spat for settlement.

The counts of small mussels from the ground samples taken at racks 5, 8 and 16 confirm that the main settlement occurred in July. During August and September the numbers of small mussels in these samples decreased rapidly, indicating not only that there was little or no further settlement but also that those which had settled were failing to survive. This result was not unexpected at rack 16, where the ground was sandy and there were no adult mussels, but at racks 5 and 8 there was a good population of adult mussels, which would have been expected to give some protection to, and better survival of, the small ones. The reduction in numbers cannot be accounted for by growth into the larger size groups. At rack 8 in July there were 464 mussels less than 4 mm in length, none between 5 and 14 mm, and only one in the 15–19 mm size group. In the August sample the number in the 0–4 group had fallen to 70 and there were still none between 5 and 14 mm in length and one in the 15–19 mm group. By September there were no mussels less than 4 mm in length, one in the 5–9 mm group and none in the 10–14 mm group. At this site mud collected under the mussels very rapidly, to such an extent that the rack soon became submerged and had to be replaced by a second one in January 1965 and a third in July 1965 (Plate 3).

CRAB PREDATION

There is no doubt that predation by crabs plays an important part in the life of young mussels. In August 1962 it was thought that the mussels at Site IV would make a useful stock for relaying and approximately half a hundredweight (25 kg) were relaid in Deganwy Harbour at about mean low-water level. Within four days every one had disappeared, although much of the shells and associated debris remained. A pair of prawn pots was left on this site for 24 hours and caught 204 crabs (*Carcinus maenas*), mainly between 30 and 60 mm carapace width, of which 184 were female.

A few laboratory observations were made of the numbers of mussels which crabs of known sizes could eat when housed in small glass aquaria in sea water and offered a selection of mussels as food. The results are summarized in Table 7. These data do not tell us much about the numbers of mussels a crab could eat but they throw some light on the size of mussel a particular size of crab can tackle. It appeared, for example, that a crab of carapace width 18 mm did not readily eat mussels larger than 9 mm in length. However, it should be mentioned that all the mussels used in these experiments were relatively quickly grown and thin-shelled. On one occasion an 18-mm crab was observed to eat five 5-mm mussels within 40 minutes, followed by a further three of 5 mm and one of 11 mm in the next hour and three-quarters.

There was evidence that a crab of 23 mm carapace width could eat mussels measuring at least up to 11 mm in length, and 30 and 33-mm crabs could eat mussels up to 14 mm in length. On the one occasion when 15 and 16-mm mussels were offered to these larger crabs they were not eaten. Although large crabs tackled larger mussels than small ones they had no difficulty in eating small mussels as well.

Shore crabs were extremely common on the mussel beds, both littoral and sublittoral, and all sizes from 2–3 mm up to 50–60 mm carapace width were present. No attempt has as yet been made to assess their numbers or the quantity of mussels they eat, but it seems likely that they are major predators—as might be expected. It seems that a spatfall is only effective when it is sufficiently plentiful to satisfy the needs of the predators and to provide a surplus to restock the beds.

Table 7 The results of an experiment to find the maximum size of mussel that a crab of a certain carapace width can eat, shown as the numbers of mussels eaten. The figures in the bold type face are the numbers of mussels presented

Crab carapace width (mm)	Period (days)	Mussel size (mm)																													
		4		5		6		7		8		9		10		11		12		13		14		15		16	
18	4					1	**2**	4	**4**	1	**3**		**1**														
18	2				**1**		**1**		**1**	2	**2**	1	**1**				**1**		**1**		**1**						**1**
18	2			15	**15**											1	**1**				**1**		**1**				
18	3	11	**11**	7	**7**	1	**2**	3	**4**	2	**3**	1	**1**		**1**						**1**		**1**				
21	3	1	**1**	3	**3**																						
23	3					1	**11**							2	**2**	1	**1**										
27	3	14	**14**	5	**5**	1	**1**																				
30	3	2	**2**	3	**3**					3	**3**	1	**1**	2	**2**	3	**3**	3	**3**	2	**2**	1	**1**				
33	3															2	**2**	1	**2**	2	**2**	1	**3**		**1**		**2**
33	3					1	**1**					1	**1**	2	**2**			4	**5**	6	**7**	4	**4**				

Plate 1 Hand gathering at Conway. The mussels are collected in wicker baskets or buckets and emptied into sacks for transport to the tanks.

Plate 2 Raking for mussels. The drogue used to keep the boat head to tide can be seen just astern of the boat.

Plate 3 A Courlene spat collector (right) and an example of the racks used for collecting spat (Rack 8). At this site mud collected under the mussels very rapidly. The original rack, now invisible, was put up in August 1964, the second rack, on the left, in January 1965, and the third, on the right, in July 1965.

Plate 4 Morfa mussel bed. August 1963: part of the area covered by the spatfall.

Plate 5 Another view of the Morfa mussel bed, August 1963.

Plate 6 The same area as in Plate 5, six months later. Note the extensive areas bare of mussels.

Plate 7 A close-up of a portion of Plate 6.

DISCUSSION

Observations were made on the settlement of mussels at Conway from 1961 to 1965. When the work started it was thought that substantial spatfalls were relatively rare, and that the supply of young mussels was a major problem in the fishery. This view does not appear to be supported by the results obtained.

In August 1961, at the one sampling site which was then in use, there were 1 420 mussels of the 0–3 mm size group in a sample of approximately 1/50 sq. metre. In August and September 1962 there were large numbers of spat mussels at all the stations which were examined. In 1963 records were obtained of two samples from Site III on 30 July and 8 October, which gave 1 200 and 16 600 spat mussels per 1/50 sq. metre respectively. 1964 seems to have been a relatively poor year for spatfall, although even then counts of almost 500 per 1/50 sq. metre were recorded; however, 1965 produced a very heavy settlement in the Green Bank area. In an area some fifty yards square mussels about 0.5 mm in length covered all the filamentous algae and were exceedingly numerous among the byssus threads of the older mussels, and in the innumerable crevices between the barnacles. These samples were taken by dredge, so a count per unit area of ground was not possible. In the same year there was also a substantial settlement on a boat moored in Conway Harbour.

In four out of the five years covered by this investigation there was a substantial spatfall in at least some part of the fishery. In 1962 this was of sufficient magnitude to satisfy the needs of the predators (chiefly *Carcinus*) and to provide a surplus which restocked the fishery. In most years it appears that the spatfall is barely sufficient to meet the demands of the predators, and there is little or no margin to provide recruits to the stock.

It is evident that the spatfall which occurred at Conway in the summer and autumn of 1962 was one of exceptional magnitude as far as this series of observations is concerned (Plates 4 and 5). The winter of 1962–63 was the most severe for 150 years. Savage (1956), discussing the great spatfall of 1940, postulated that there was a connection between cold winters and heavy mussel spatfalls, and some discussion of this will not be out of place here.

There is a strong similarity between 1940 and 1963 in that in both years a heavy settlement of mussels a few mm long became apparent in March or April, and in both cases this followed an exceptionally cold winter. It is important to appreciate that in 1940 the first observation recorded by Savage was 'The spat was first noticed during April attached to mussels brought to the Conway Purification Tanks . . . . .'. Although later in his paper he discusses the factors that may have led to a mass spawning in the spring of 1940 no observations of spawning (i.e. release of gametes) were made. There is a tacit assumption that the appearance of mussels 2 mm long was preceded by spawning a few weeks earlier. In 1963 mussels 2–3 mm long became apparent in March, but the adults had exceptionally good meats throughout the spring of that year, which makes it unlikely that there had been a mass spawning early in 1963. There was a very heavy settlement of mussels about 1 mm long during the previous summer and autumn, and there is no doubt that the small mussels which became apparent in March 1963 were the survivors of the 1962 spatfall, and of a spawning in May or June 1962, if we accept the evidence of Chipperfield (1953) and Bayne (1964) that the majority of mussels in an area spawn at the same time or within a short period. Whether the very cold winter of 1962–63 had any influence on the numbers of survivors is not clear from the evidence available.

The suggested connection between heavy spatfalls and cold winters appears to rest on very few observations. Harding (1884) refers to a heavy spatfall seen in May 1879 after a very severe winter, and there is the case of 1940 referred to by Savage. It is significant that in 1947 there was a severe winter but 'no great settlement of spat' (Savage 1956) at Conway. Although there was a great abundance of young mussels in the Conway fishery in 1963, only a few miles away, in the Menai Straits, there was no sign of a similar blanket spatfall. It seems that at present we have insufficient information on the variations in intensity and extent of mussel spatfall from one year to another to draw any conclusions as to their connection with the weather.

PART II
OBSERVATIONS ON THE SUBLITTORAL MUSSEL BEDS AND A NOTE ON GROWTH-RATES

INTRODUCTION

Work on the intertidal mussel beds at Conway is described in Part I of this paper. In the autumn of 1964 it was decided to turn attention to the sublittoral beds.

A general echo sounder survey was made on 23 September 1964 by a number of straight runs over the beds, using leading marks and cross bearings to locate the end of the runs. The echo sounder was run continuously on each traverse and the depth was read off the trace afterwards. For this purpose the datum used was the fact that, at that time, the 'Scabs' just ebbed out on a 30 foot (Liverpool) tide. From this it was found that the depth of water at No. 5 buoy was about 4 feet below datum. Many of the sounding runs started or finished at No. 5 buoy, which enabled the datum level on each trace to be adjusted for the change in tidal height during the survey.

The extent of the underwater mussel beds was determined by sampling with a long rake where possible, and with a 2-foot Baird dredge in the deeper water. The positions of the salient features of the mussel beds, and of the navigation buoys, were fixed by means of sextant readings on well-defined land marks. On the sketch maps the low-water mark used is that of the Ordnance Survey 6-inch map, adjusted as necessary to fit in with the soundings of the survey. In Figure 3 are shown the soundings and the general distribution of the mussel beds, broadly divided into those areas mainly populated with small mussels and those where mussels of marketable size were found. The underwater distribution of mussels may, however, be more extensive than is indicated by this map.

In January 1965 a series of six-monthly dredge surveys was started, with the object of determining the size composition of the stocks of mussels in the various parts of the river. The samples were collected by means of two-minute hauls with a naturalist's dredge, which had a rigid bag made of $\frac{1}{4}$-inch wire mesh. Three such surveys were made: in January 1965, June 1965 and January 1966. In order to simplify comparisons of one survey with another, the area was divided into seven major beds (Figure 4), and the dredge hauls for each bed have been pooled together. In Table 8 are shown the size compositions, in 10-mm groups, of the mussel population in each major bed for each of the three surveys. For the purposes of expressing the numbers of mussels in the different groups as percentages of the total, those under 10 mm were ignored; the reason for this is that this group is liable to such tremendous variations during a spatfall that its inclusion would, on occasions, distort the picture. There were also occasions when it was quite impossible to obtain a count of the numbers of very small (less than 1 mm) mussels present. Moreover, it has been found that so few of these small mussels survive that they can hardly be said to have entered the fishery until they reach a size of about 10 mm in length.

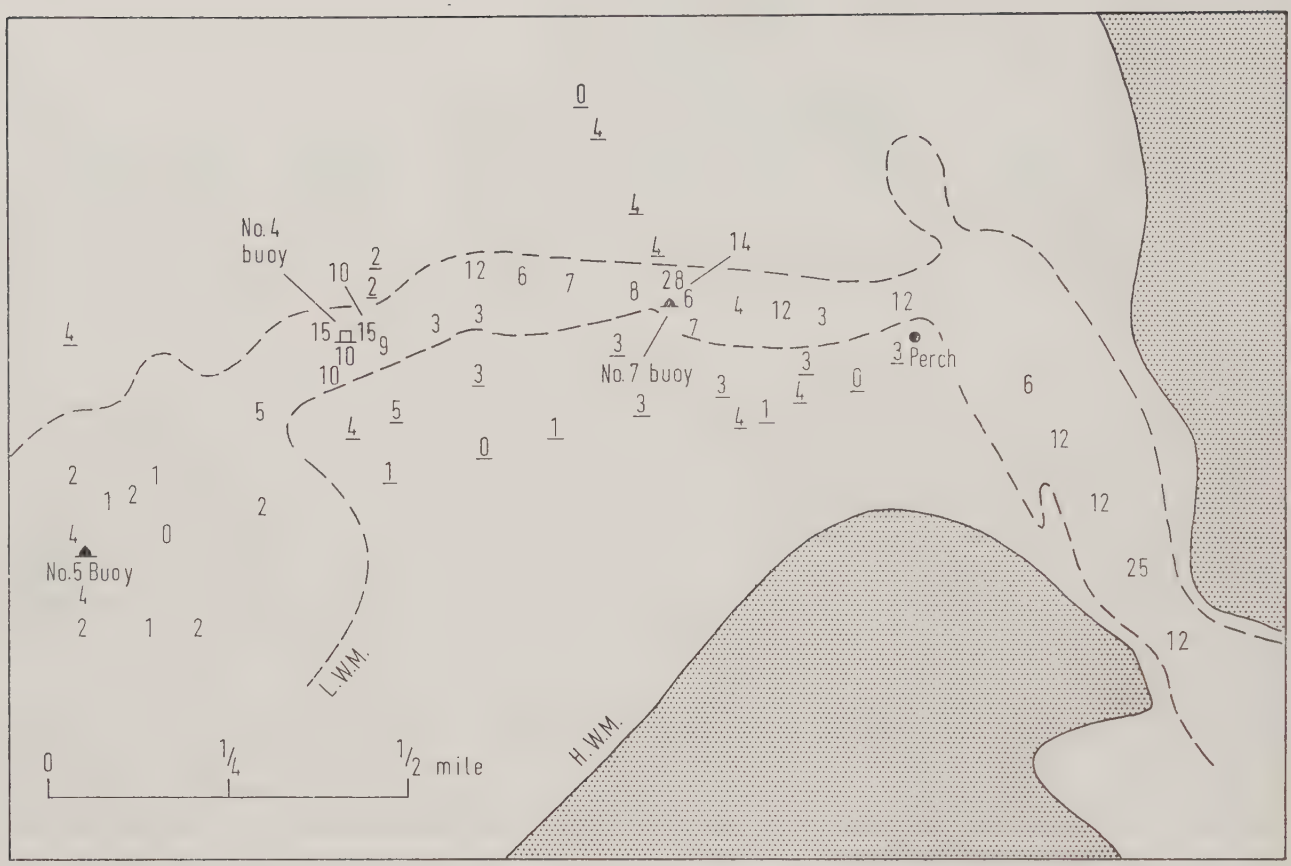

Figure 3 Two sketch maps of the Conway estuary, showing: *Above* the soundings, in feet, and the heights above datum (underlined), taken on the mussel beds; *Right* the general distribution of mussels of different sizes.

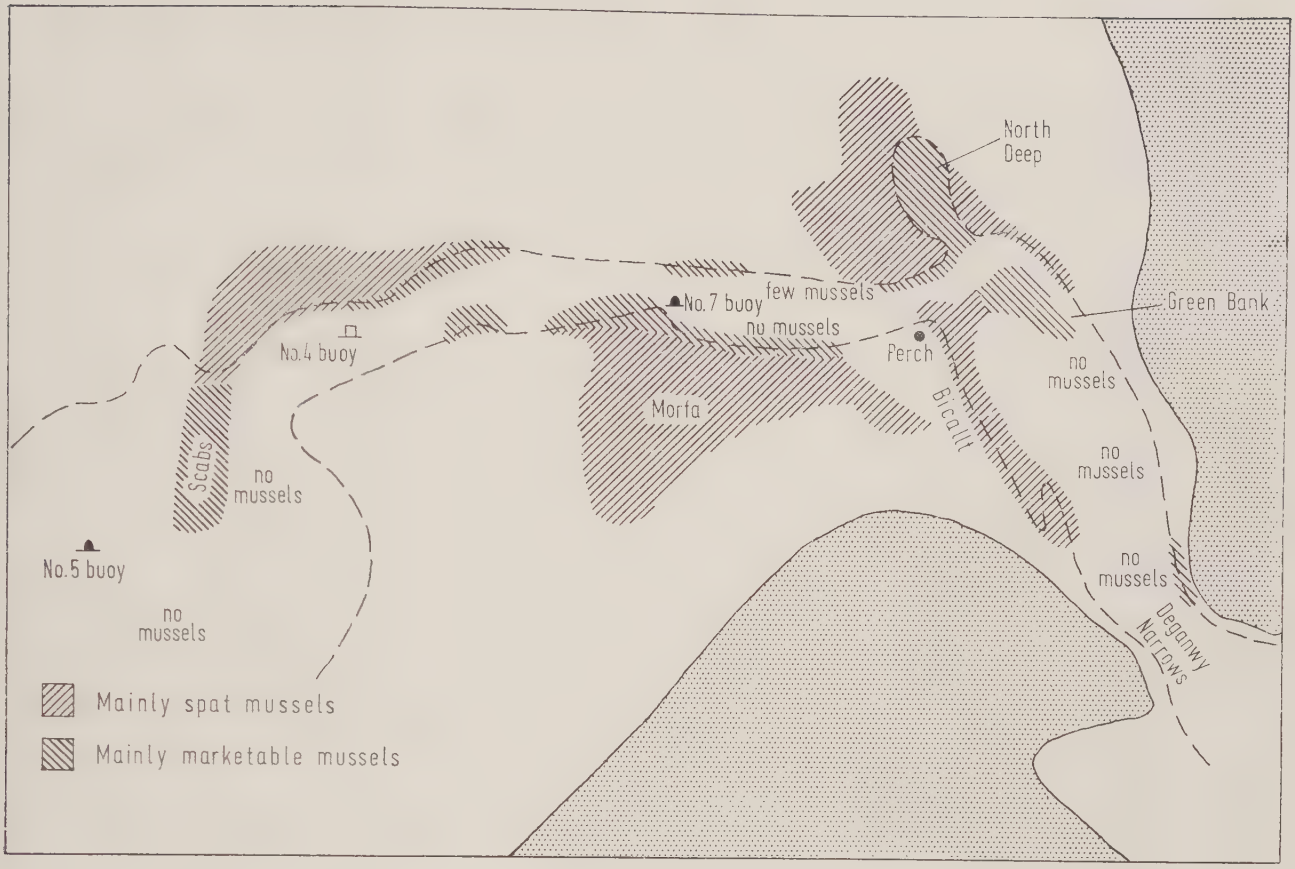
North Deep
Green Bank
No. 7 buoy
few mussels
no mussels
No. 4 buoy
Perch
Morfa
Bicalt
Scabs
no mussels
no mussels
no mussels
no mussels
No. 5 buoy
no mussels
Deganwy Narrows
Mainly spat mussels
Mainly marketable mussels

Table 8 The size compositions of the mussel population on various beds for the three surveys

Bed	Size group (mm)	Jan 1965 No.	%	June 1965 No.	%	Jan 1966 No.	%
Scabs	*0– 9*			*6*		*124*	
	10–19			1	1.9	0	0
	20–29	3	5.3	2	3.7	3	4.3
	30–39	4	7.0	7	13.0	5	7.1
	40–49	3	5.3	5	9.3	5	7.1
	50–59	12	21.0	19	35.2	31	44.3
	60–69	23	40.3	11	20.4	23	32.9
	70–79	8	14.0	8	14.8	2	2.9
	80–89	3	5.3	1	1.9	1	1.4
	90–99	1	1.8				
Total	10–99	57		54		70	
Cae Gonwy	*0– 9*	*0*		*9*		*54*	
	10–19	4	6.5	2	3.4	0	0
	20–29	2	3.2	2	3.4	0	0
	30–39	3	4.8	21	36.2	15	13.3
	40–49	17	27.4	7	12.1	67	59.3
	50–59	16	25.8	8	13.8	26	23.0
	60–69	17	27.4	9	15.5	5	4.4
	70–79	3	4.8	8	13.8		
	80–89			1	1.7		
Total	10–89	62		58		113	
Deeps	*0– 9*	*127*		*324*		*2 078*	
	10–19	55	8.1	68	8.1	31	5.2
	20–29	79	11.7	87	10.4	50	8.4
	30–39	72	10.6	167	19.9	55	9.2
	40–49	92	13.6	125	14.9	126	21.2
	50–59	110	16.2	136	16.2	165	27.7
	60–69	125	18.5	128	15.3	102	17.1
	70–79	110	16.2	102	12.2	52	8.7
	80–89	34	5.0	23	2.7	14	2.4
	90–99			2	0.2		
Total	10–99	677		838		595	

Table 8—continued

Bed	Size group (mm)	Jan 1965 No.	%	June 1965 No.	%	Jan 1966 No.	%
Green Bank	*0– 9*	*297*		*Uncounted*		*2 308*	
	10–19	75	20.7	16	10.4	20	10.8
	20–29	94	25.9	24	15.6	19	10.3
	30–39	49	13.5	19	12.3	20	10.8
	40–49	21	5.8	9	5.8	39	21.1
	50–59	22	6.1	20	13.0	67	36.2
	60–69	46	12.7	25	16.2	8	4.3
	70–79	43	11.8	35	22.7	8	4.3
	80–89	12	3.3	6	3.9	2	1.1
	90–99	1	0.3			2	1.1
Total	10–99	363		154		185	
Bicallt	*0– 9*	*46*		*133+*		*317*	
	10–19	20	19.2	11	7.6	6	5.5
	20–29	21	20.2	8	5.5	1	0.9
	30–39	22	21.2	33	22.8	14	12.8
	40–49	5	4.8	38	26.2	30	27.5
	50–59	6	5.8	15	10.3	41	37.6
	60–69	12	11.5	14	9.7	9	8.3
	70–79	12	11.5	24	16.6	6	5.5
	80–89	6	5.8	2	1.4	2	1.8
Total	10–89	104		145		109	
Narrows	*0– 9*	*220*		*Over 300*		*359*	
	10–19	112	13.6	127	17.9	8	7.1
	20–29	217	26.3	102	14.4	1	0.9
	30–39	346	42.0	238	33.6	6	5.3
	40–49	59	7.2	159	22.5	27	23.9
	50–59	33	4.0	31	4.4	53	46.9
	60–69	27	3.3	24	3.4	12	10.6
	70–79	23	2.8	23	3.2	2	1.8
	80–89	7	0.8	4	0.6	4	3.5
Total	10–89	824		708		113	

Table 8—continued

Bed	Size group (mm)	Jan 1965 No.	%	June 1965 No.	%	Jan 1966 No.	%
Morfa Bach	*0– 9*	*Not sampled*		*Several hundred*		*60*	
	10–19			25	19.1	–	
	20–29			24	18.3	1	2.4
	30–39			56	42.7	3	7.1
	40–49			22	16.8	14	33.3
	50–59			0	0	19	45.2
	60–69			1	0.8	4	9.5
	70–79			2	1.5	1	2.4
	80–89			1	0.8		
Total	10–89			131		42	

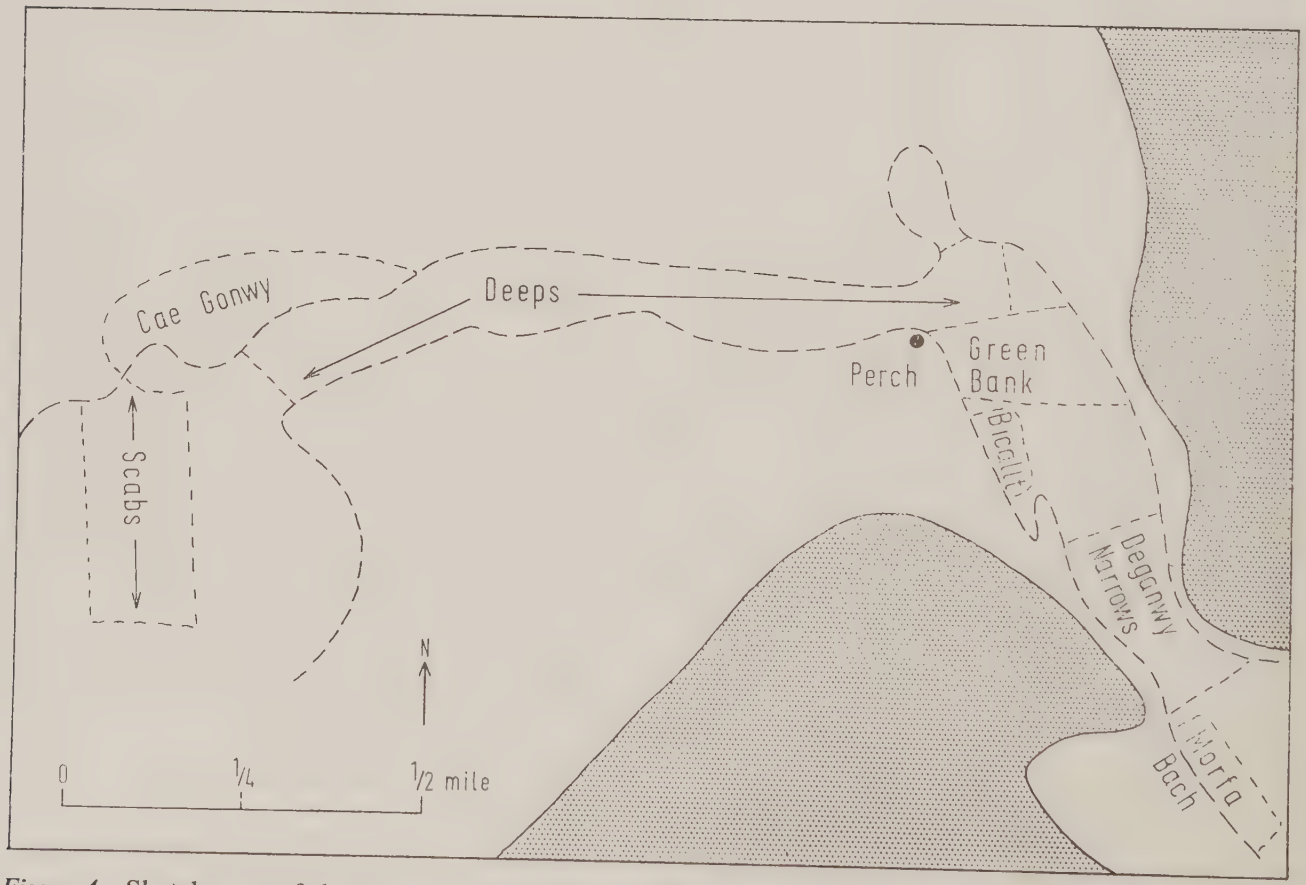

Figure 4 Sketch map of the Conway estuary, showing the seven major sublittoral mussel beds.

SIZES OF MUSSELS ON THE MAJOR SUBLITTORAL BEDS

The Scabs This was the most seaward of the Conway mussel beds, and consisted of a gravel ridge which ran across the main channel. On the biggest spring tides the highest points ebbed out, but most of the bed was always under water. There was no accumulation of mud here. At the start of the investigations the population consisted mainly of large mussels; those of 80 mm or more in length did not appear to be old—they were well fished and had the sharp end and tortoise-shell markings that are characteristic of quickly-grown mussels. This area was a good one for growth, but settlement of young mussels was scanty. There was some settlement between June 1965 and January 1966.

Cae Gonwy This bed was continuous with the northern end of the Scabs but was essentially an intertidal bed; for convenience, one may take the low-water mark as the boundary. The ground here was of pebbles rather than gravel and there were substantial rocks on the seaward end of the bed. The general size of the mussels was smaller than on the Scabs. The higher parts were populated mainly by mussels from the 1962–63 spatfall. The parts sampled in these surveys (near to low-water mark) carried a greater variety of sizes, still with a substantial proportion of the 1962–63 brood, about 30–50 mm in length. A small number of spat were found in the January 1966 survey.

The Deeps This was the largest of the beds and extended from No. 4 buoy to a little beyond the Perch; only those parts lying below low-water mark are considered here. The north bank of the channel was very steep and depths of 15–20 feet were found only a few yards from low-water mark, but the slope of the south bank was very gradual. Much of the bottom was of coarse gravel and stones, especially towards the western end. About 100 yards west of the Perch was a region of loose shifting sand which extended from the south side to about half-way across, and in which there were no mussels.

Because of the considerable extent of the Deeps many dredge hauls were made in this area, and the total number of mussels collected was higher than in any of the other beds. At the time of the first survey there was a preponderance of mussels between 50 and 80 mm in length; here again the large ones had the appearance of having grown quickly. Six months later there was an increase in the numbers of mussels 30–50 mm long, and these, too, had thin shells with tortoise-shell markings, which would suggest that they were about a couple of years old; their increase was of particular interest because about six tons of mussels of this size had been relaid in this area in May 1965. It would be tempting to think that the increase was a result of the relaying, but there was good reason to doubt this. The mussels that were relaid had black shells and after two months' growth in the new environment would be expected to show a distinct 'shoot'. No such mussels were found in the Deeps, although a few were found in Bicallt (see below).

The Deeps contained a higher proportion of small mussels than the beds already discussed. It will be seen from Table 8 that between June 1965 and January 1966 there was a very considerable influx of very small mussels; although they are shown as being in the 0–9 mm group, in fact the great majority were less than 3 mm in length. The large number of them, over 2 000, compared with 595 between 10 and 89 mm, would suggest a spatfall of some substance.

Green Bank In this context 'Green Bank' was taken to include the whole width of the channel. A few years ago this bank was well-defined and situated towards the eastern side of the channel; more recently it had become lower, but at the same time had spread right across to the Perch. The ground was composed of sand and gravel, bound together with mussel byssus; there was now little mussel mud present.

The population here contained a greater proportion of the smaller sizes of mussel than the beds previously discussed. In the first survey, for example, the population showed three peaks, 0–9 mm, 20–29 mm and 60–80 mm. The most striking feature of the June 1965 survey was the very heavy settlement of mussels 0.5 to 1 mm in length in this area. These were particularly numerous on filamentous algae and bryozoa, many of the filaments being completely covered by young mussels. The spat were also present in vast numbers among the byssus threads of the adults and attached directly to mussels, shells, stones, etc. This particular settlement appeared to have occurred only in the Green Bank area. Six months later (January 1966) the numbers of these small mussels had greatly decreased, but approximately 2 300 were found in

the 0–9 mm size group. It is thought likely that the increase in numbers of this size group in the Deeps also had its origin in this settlement on Green Bank. During the June 1965 survey large numbers of berried crabs were found on Green Bank, as many as a dozen in a two-minute dredge haul. Whether there was any connection between the heavy spatfall and the concentration of crabs is not known.

Bicallt Bicallt is a small bed on the west shore of the channel between the Perch and Deganwy Narrows. Above the low-water mark it is much built up with mussel bed, but below low-water mark, where the samples were taken, the ground is firm gravel. Small mussels were again well represented, and in the samples of June 1965 and January 1966 the predominant size groups were between 30 and 60 mm. In June 1965 were found about three dozen mussels of the 30–50 mm size range which had the black shell and definite 'shoot' which would be consistent with their having been relaid two months previously.

Deganwy Narrows This bed extends right across the channel, but very few mussels were found in the middle; they were mainly within a few yards of either bank. The banks are steep, gravel on the west and pebbles on the east shore. In the first survey most of the mussels were less than 40 mm in length. Twelve months later the main mode in the size composition of the population was between 40 and 70 mm, and there had been a substantial settlement of small mussels.

Morfa Bach There was a small bed separated from the Narrows by a gutter and extending as far upstream as the Morfa Outfall. Most of the bed was above low-water mark and had built-up mud-banks several feet thick; below low-water mark the ground was a hard scoured gravel with a rather sparse mussel population. The samples were taken along a line near to low-water mark, this being necessary because the space was restricted by the bank on the one hand, and a line of moorings on the other. It was possible that the substantial difference in size composition between the June 1965 and the January 1966 samples may have been due to variations in the position of the dredge haul in respect of low-water mark. The hauls taken outside the line of moorings did not yield any mussels.

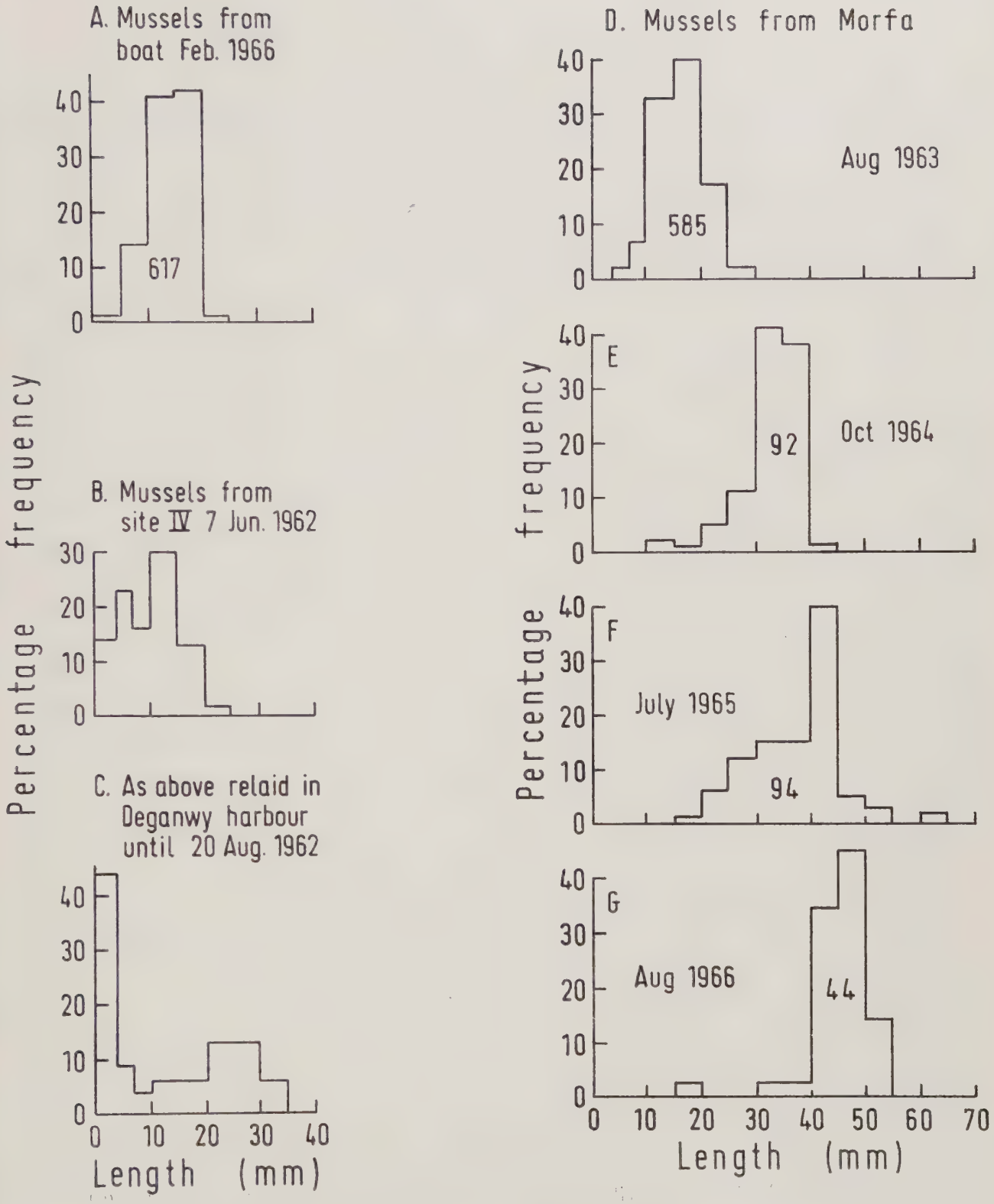

Figure 5 Growth of mussels in the Conway estuary, as indicated by the size composition of: (A) a sample of mussels, not more than ten months old, taken from the hull of a boat in February 1966; (B) and (C) a sample of mussels from Site IV which were relaid in Deganwy Harbour from June 1962 until August 1962; (D) to (G) the size composition, in successive years, of the population of mussels which settled on the Morfa in 1963.

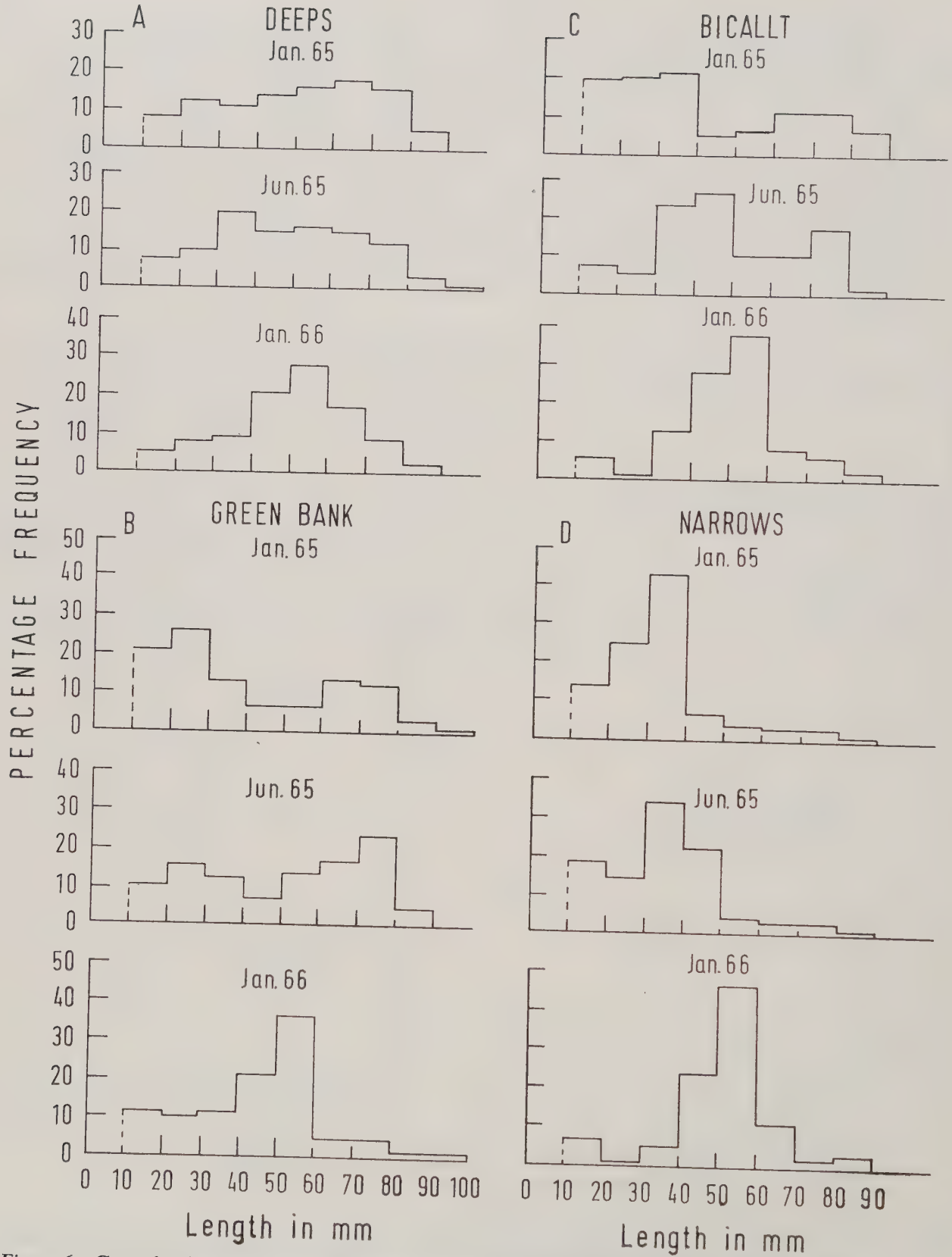

Figure 6 Growth of mussels in the Conway estuary, as indicated by the size compositions of the populations on four sublittoral beds in the period January 1965–January 1966.

RATE OF GROWTH OF MUSSELS

It is extremely difficult, if not impossible, to assess the age of an individual mussel unless its history is known, because the shell does not bear annual rings such as are found in the cockle or the escallop. For this reason our knowledge of the growth-rate of mussels is limited, and it may be useful to record here some data which were acquired in the course of the investigation.

In February 1966 the local boat-yard reported that they had found a heavy settlement of mussels on a boat which had just been brought in. This boat had been put on its moorings at Easter 1965 and had remained there throughout the following ten months. Hence the mussels could not have been more than ten months old, and may have been only six to eight months old, when we examined them. A sample of 617 was measured, and as can be seen from the histogram in Figure 5A, the great majority were between 10 and 20 mm in length.

In June 1962 a sample of mussels from Site IV was relaid at about low-water mark in Deganwy Harbour and protected from crabs by courlene netting. Before relaying, the main peak of the population was in the 10–15 mm range; two-and-a-half months later this peak had moved across to the 20–30 mm size range (Figure 5B, C) and there had also been a considerable settlement of mussels of the 0–3 mm group.

Information is also available on the rate of growth of the spat which settled on the Morfa in 1963. This population was, strictly speaking, derived from the 1962 spawning and settlement, but to maintain conformity with the more common observations made with the naked eye it may be convenient to refer to it as the 1963 spatfall. The size composition of this population in successive years is shown in Figure 5D–G; it will be seen that growth was rapid during 1963 and 1964, but after that it slowed down very considerably, and in 1966 the average increase in length was of the order of 2–3 mm. This very slow growth-rate is to be accounted for by the accumulation of mud underneath the mussels, which caused them to be out of the water for up to four hours per tide. The rate of build-up of the mud was observed at rack 8, which was first erected in August 1964; as the mud built up round it, it became too low to be useful and a second rack was put in in January 1965. By early July 1965 the first rack was completely buried, the second was almost submerged, and a third rack was in use. At this particular place the mud rose over two feet in ten months. A similar quantity of mud was accumulated over a wide area. This mud does not provide a secure anchorage for the mussels and so the bed became unstable and very vulnerable to wave action. During rough weather large patches of the carpet of mussel may be washed away, as in Plate 6 which was taken about eighteen months after the settlement had occurred. A close-up view is shown in Plate 7.

The mussels below low-water mark are a very mixed population, which makes it more difficult to isolate a particular year-class, and follow its growth. The combined effects of a mixed population, a high growth-rate and intensive fishing, tend to obscure the picture. However, if the percentage frequencies of the various size groups for the mussel beds, as given in Table 8, are plotted as histograms (Figure 6), results are obtained which are very suggestive of a growth-rate of 20 mm per annum for mussels 25–35 mm in length living below low-water mark of spring tides in the River Conway. This growth-rate is similar to that found by my colleague G. Davies in his experiments in the Menai Straits. The picture is perhaps clearest for the samples gathered from the Deganwy Narrows (Figure 6D). In January 1964 there was a well-defined peak at 30–40 mm, and in June the main peak was still in the same range, but there was an increase in the numbers in the 40–50 mm range; in January 1966 the main peak was the 50–60 mm range. A similar tendency can be seen in the histograms of the other beds; in the Bicallt mussels, for example, a broad peak at 10–40 mm moves across to become a reasonably well-defined one at 50–60 mm twelve months later. This picture is also fairly clear for the Green Bank samples, but not so well-defined for the Deeps. During this period the main change in the population in the Deeps was the removal of the large mussels. If we accept that those up to 60 mm long in January 1966 developed from those less than 40 mm long in January 1965, it follows that most of those which were above 40 mm long in January 1965 were removed from the fishery in the next twelve months. The histograms for the other beds also show this removal of large mussels during the year 1965. The shortage of marketable mussels in the fishery in the beginning of 1966 was confirmed by the very low output at that time.

The data given above make possible an estimate of the time taken for mussels growing below low-water mark in the River Conway to reach market size. Those which settle in the early summer can reach a size

of 10–20 mm within twelve months. Mussels of 10–20 mm in length can grow to 30–40 mm in twelve months (Figure 5D, E), and can increase their length by a further 20 mm in the next year. Thus, at the end of three years they can be 50–60 mm long, which is just above the minimum legal size but not quite up to the size desired by the markets. A further season's growth would be needed to achieve this, a total of four years. On this basis one would expect the heavy spatfall of the autumn of 1962 to give rise to an increase in the numbers of marketable mussels in the sublittoral beds in the 1966–67 and subsequent seasons. This expectation has been borne out in practice, the output having risen from 5 255 bags in 1965–66 to 8 076 bags in 1966–67 and 9 884 bags in 1967–68.

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